(400 images per FD), while anisotropic textures had dominating directions of 120° and 30° (400 images per direction). For those images, three parameters at scales ranging from 2 to 7 pixels (depending on image size) were calculated, i.e. FS along the direction of the texture roughest part (FS_{Sta}), aspect ratio (StrS) and direction signatures (StdS), respectively. The aspect ratio and direction measure the texture anisotropy. We also evaluated our method for its sensitivity in differentiating the bone texture between subjects with and without radiographic hand OA. The subjects were taken from the Osteoarthritis Initiative (OAI) public use data set (OAI Datasets 0.2.2 and 0.C.1). Images from centre A were used since they exhibit smallest size amongst the five centres (150 DPI). This strategy allows for testing "the worst scenario", i.e. 20 × 20 pixel regions. We used 20 pairs of subjects (n = 20, 14 women) with (OA cases) and without (controls) OA in the 5th distal interphalangeal (DIP5) joint. OA was defined as: (i) joint space narrowing (JSN) grade 2 or worse, (ii) osteophyte grade 2 or worse, or (iii) JSN grade 1 with an osteophyte grade 1. These criteria approximate Kellgren and Lawrence (K/L) grade 2 or worse. The case-control pairs were individually matched by sex, age, body mass index and race. For each hand x-ray, 20 × 20 pixels bone texture regions were selected on the distal and middle phalanges adjacent to the DIP5 joint (Fig. 1). For each bone region, the FS_{Sta}, StrS, StdS parameters were calculated at scales of 0.34 and 0.51 mm. One-way analysis of variance ANOVA with Tuckey HSD (Games-Howell if appropriate) post hoc tests and paired samples t-tests (Wilcoxon signed-rank tests if appropriate) were used ($p < 0.05$ is significant).

Results: For all image sizes and scales, values of FS_{Sta} were statistically significantly different between isotropic fractal images. StrS values obtained for anisotropic surfaces were lower than those for isotropic surfaces, and StdS agreed with the dominating directions. Compared to the controls, OA middle phalanges exhibited significantly lower FS_{Sta} at sizes 0.34 and ($p = 0.018$) and 0.51 mm ($p = 0.021$), and higher StrS at 0.34 ($p = 0.015$) and 0.51 mm ($p = 0.002$). In the distal phalanx, FS_{Sta} at size of 0.34 mm ($p = 0.044$) was lower for OA cases than controls.

Conclusions: The AVOT method can differentiate between small isotropic and anisotropic fractal textures, and also between finger bones with and without radiographic OA. Although further large-scale studies are still required, our results show the potential of the method for the quantification of OA changes in the finger bone structure.

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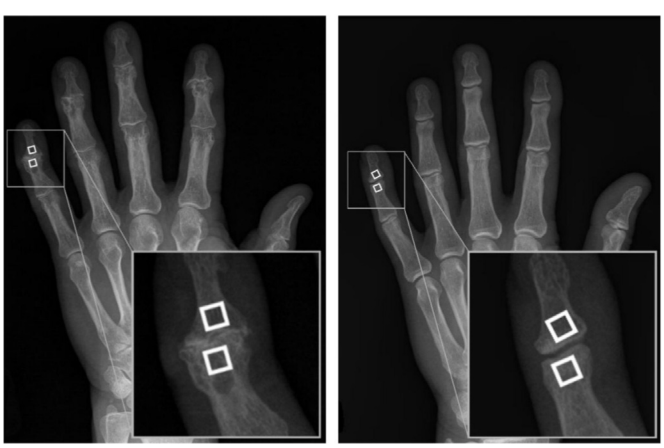

Fig. 1. X-rays of hands (*left*) with and (*right*) without radiographic OA in the DIP5 joint. White squares are bone texture regions selected.

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QMRI-BASED RISK FACTORS FOR SYMPTOMATIC KNEE PAIN: DATA FROM THE OAI

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Purpose: Chronic knee pain is a common feature of osteoarthritis (OA); the pain may be associated with different risk factors and may have various etiologies. The purpose of this work was to determine which MR imaging characteristics can be used as risk factors - or imaging biomarkers - for the subsequent development of symptomatic knee pain.

Methods: Right knees from an Osteoarthritis Initiative (OAI) cohort with untreated right knee pain were examined. This medication free cohort had right knee pain symptoms recorded as "Pain most days of a month in past 12m" (RKSX = 2) on observations later than the 12 month visit (V01). At the screening visit (P1), the 12 month visit (V01) control subjects had lower symptomatic scores (RKSX = {0,1}). A control group with no right knee pain was matched for age, BMI, gender and no therapy. Only subjects with DESS MRI images were analyzed. The MRI DESS analysis was done by Qmetrics technology software that automatically segmented the femoral, tibial and patellar cartilage into several regions of interest (ROI): femur, tibia, patella, central medial femur, central lateral femur, medial tibia, lateral tibia, medial trochlea, lateral trochlea, medial patella, lateral patella. Automated segmentations that failed to correctly segment cartilage tissue were removed from the analysis. Each ROI was quantitated for volume, area, thickness, curvature and DESS signal contrast properties. ROI Statistical descriptors were computed for thickness, curvature and contrast. Using the control subjects, all measurements were adjusted for BMI, age and gender differences. The measurements then were z-transformed using the rank inverse normal transform. Finally, all measurements were categorized as low-control-quartile ($p < 0.25$), mid-control-range (0.25 to 0.75) and top-control-quartile ($p > 0.75$). The time to pain event (RKSX = 2) on cases and the time of last observation were used in Cox-Survival-Models. A bootstrapped-step-wise feature selection algorithm based on the Integrated Discrimination Improvement (IDI) was used to extract a robust multivariate COX-survival model from the 12 month observation (V01). The COX-model categorized subjects into high risk and low risk to develop future knee pain. All models were internally validated using a 10-fold cross-validation. Furthermore, the risk model was tested in the baseline observation and the 24 month observation.

Results: 80 cases qMRI (39:41 Males:Females), with successful right knee segmentations were included. 194 qMRI analysis (87:107 Males:Females) were used as controls. The total population had an average age of 62.9 ± 9.5 years and BMI of 27.0 ± 4.4. There was no statistical difference between study subjects and controls for BMI and age. Table 1 shows the six MRI features that separate subjects into high/low risk for the development of chronic pain at the three starting points. The femur curvature was a consistent risk factor: Odds ratio (OR) 1.92 (1.5 to 2.5). Also constant predictive was the bone-cartilage signal contrast of the lateral femur: 2.42 (2.0 to 2.85). Figure 1 shows the Kaplan-Meier plots of the Baseline, 12 Month and 24 Month visits.

Conclusions: Abnormal curvature of the femur and low DESS signal contrast at the lateral femur articular surface are risk factors for the development of knee pain. Although the casual relationship of these findings with the evolution of OA still has to be established, this fact may be used to make clinical and treatment decisions for the prevention of symptomatic knee pain.

Table 1

qMRI-based risk factors for Symptomatic Knee Pair. (−) low quartile, (+) at top quartile.

Feature	Cases mean (std)	Control mean (std)	One Year Odds Radio (95 CI)	Baseline Odds Ratio (95 CI)	Two Year Odds Ratio (95 CI)
Femur Curvature (Trimmed)	0.040 (0.006)	0.041 (0.006)	1.92 (1.51 to 2.50)(-)	1.64 (1.25 to 2.13)	1.36 (1.13 to 1.69)
cLF Superficial Contrast (5%)	−37.10 (1.236)	−3.918 (1.185)	2.42 (2.02 to 2.85)	1.74 (1.38 to 2.25)	1.89 (1.58 to 2.30)
Tibia Deep Layer Contrast (std)	1.154 (0.129)	1.116 (0.113)	0.52 (0.27 to 0.89) (−)	0.95 (0.60 to 1.50)	1.19 (0.60 to 2.15)
Lateral Trochlea Curvature (Trimmed)	0.029 (0.007)	0.029 (0.005)	1.73 (1.40 to 2.18) (+)	1.34 (1.09 to 1.65)	1.36 (1.11 to 1.71)
Femur Superficial Contrast (Mean)	2.281 (0.665)	2.607 (0.514)	3.27 (1.92 to 5.61)	2.07 (0.86 5.08)	1.23 (0.62 to 2.31)
Femur Curvature (Mean)	0.030 (0.006)	0.032 (0.005)	0.21 (0.09 to 0.49)	0.75 (0.39 to 1.37)	0.60 (0.26 to 1.22)

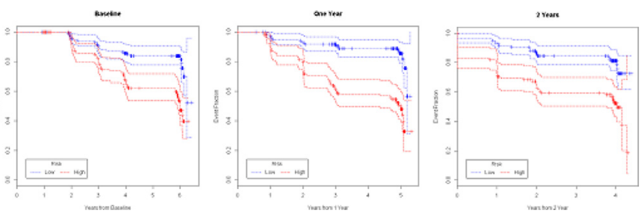

Fig. 1. Kaplan-Meier of the low-high risk groups derived from Cox-models. Left, Kaplan-Meier from the baseline observation. Middle, Kaplan-Meier that start at the one year visit (V01). Right, Kaplan-Maier starting at the 24 month visit (V03).

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LOCATION-SPECIFIC HIP JOINT SPACE WIDTH FOR PROGRESSION OF HIP OSTEOARTHRITIS: PREDICTIVE VALIDITY AND RESPONSIVENESS OF A NEW COMPUTERIZED MEASURE

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Purpose: Responsive measures of radiographic joint space width (JSW) in hip osteoarthritis (OA) are important for the evaluation of treatment interventions. To date, quantitative measures of JSW have only shown a weak relationship with symptoms and predictive validity and moderate responsiveness. One problem may be that these measures rely primarily on identifying the site of minimum JSW (mJSW), which can vary within and between readers and can be at different locations on serial radiographs. At the knee, location-specific measures of JSW have overcome these problems and can outperform mJSW. A similar method is now evaluated at the hip. The primary purpose of this study was to evaluate predictive validity and responsiveness for hip JSW measured at 3 fixed locations in the superior hip joint by a semi-automated quantitative software tool.

Methods: A nested case-control study was conducted among subjects from the Osteoarthritis Initiative (OAI), a longitudinal cohort study of knee OA. OAI participants also had standing AP pelvis radiographs at baseline and 48 month visits using a standardized protocol. We examined baseline to 48 month responsiveness in two groups of subjects who had AP pelvis films at 0 and 48 months. First, we identified subjects who had a total hip replacement (THR) after the 48 month visit (at 60 and 72 months) ($n = 27$). Second, a larger sample of cases was selected that included all subjects who had a THR at any point (12–72 months) after baseline. For this group, the contralateral (CL) hip from the THR was designated the case hip. In both groups, subjects were matched (1:1) on age and gender with subjects who did not receive a THR and reported no hip pain. In addition, the CL hip group ($n = 79$) were examined for the presence of pain from baseline to 48 months, in order to compare JSW change in those with and without pain. Measurements of superior hip JSW were made at 3 fixed locations. Location 1 was in the superior-lateral hip joint space and was 10° from a reference line that extended from the femoral head centre to the outer edge of the acetabular roof (lateral line in Fig. 1). Location 2 was 30° (superior-middle) and location 3 (superior-medial) was 50° from the reference line. Measurement was facilitated by software that delineated the femoral head and found the acetabular margin along each of the 3 lines. A reader used software to correct the output if needed. Statistical analysis. Sensitivity to change was estimated by the standardized response mean for change from baseline to 48 months. Paired t-tests were used to test statistical significance between cases and controls.

Results: The overall sample was 47% male, 91% Caucasian had a mean age of 64.2 and BMI of 27.9. Significant differences in responsiveness were observed between cases and controls in both case-control groups. The superior-medial (10° from the reference line) and superior-lateral location (50° from the reference line) were the most responsive to change in JSW. Reading time was approximately 1 minute per hip. Of the 79 subjects how underwent THR during the 6-year study period, 17 reported pain in the contra-lateral hip. Those with pain had significantly greater baseline to 48 month change in JSW and responsiveness at locations 1 and 3 than those without pain (Table 1, Fig. 2).

Conclusion: This study provides evidence that a new computer-assisted rapid method of hip JSW has predictive validity and good responsiveness. It is also rapid, taking approximately one minute per hip. In addition to detecting large 4-year changes in those undergoing subsequent THR (compared to controls), the method showed statistically significant differences in 4-year change in the contralateral hip of THR cases. Lastly, amongst the contralateral hip group, the method detected significant JSW changes in those with pain versus those without pain. Location 1 (superior-lateral hip joint) and location 3 (superior-medial hip joint) were the most responsive in all groups and warrant further study. Location-specific measures of JSW are a rapid and possibly improved method to assess hip OA.

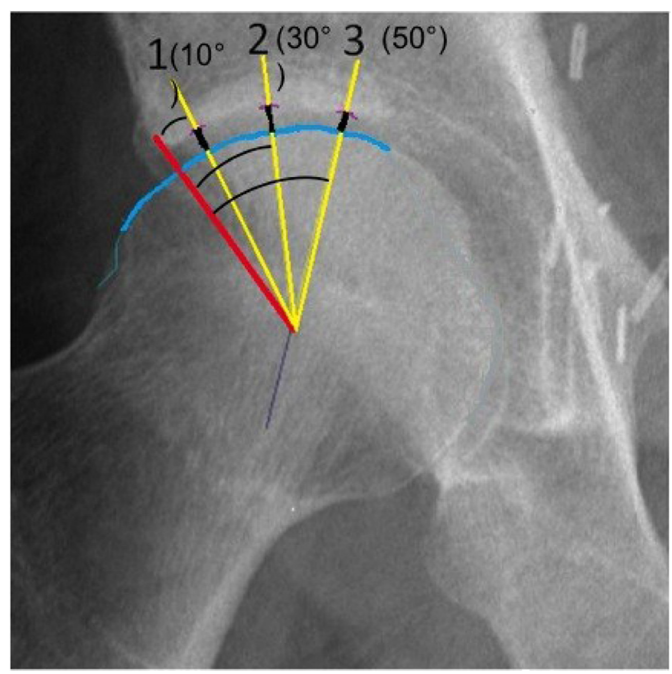

Fig. 1. Example of hip JSW measurement.

Case group 1 - hip that received THR after 48 m	Mean (sd) ΔJSW Location 1 (sup-lat)	Mean (sd) ΔJSW Location 2 (superior)	Mean (sd) ΔJSW Location 3 (sup-lat)	SRM Location 1 (sup-lat 1)	SRM Location 2 (superior)	SRM Location 3 (sup-lat)
THR Cases (n = 27)	−1.51 (1.42)	−1.25 (1.60)	−1.29 (1.24)	−1.06	−0.78	1.04
Controls (n = 27)	−0.03 (0.53)	−0.08 (0.54)	0.01 (0.50)	−0.06	−0.15	0.02
P-value	**0.000**	**0.001**	**0.000**			
Group 2 - contra-lateral hip of THR hip						
Cases (n = 79)	−0.23 (0.68)	−0.24 (0.63)	−0.40 (0.75)	−0.34	−0.37	−0.53
Controls (n = 79)	−0.03 (0.46)	−0.03 (0.81)	−0.13 (0.60)	−0.07	−0.04	−0.21
p-value	**0.03**	**0.07**	**0.01**			